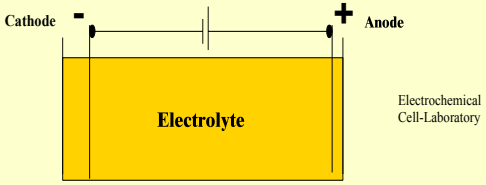
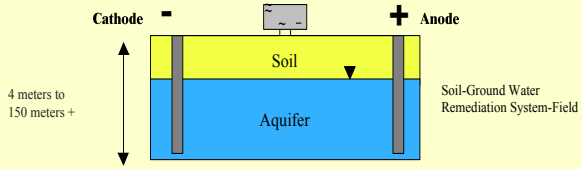



[2]Weiss Associates
[1]ecp, LLC
[3]Electro-Petroleum Inc.

# ELECTROCHEMICAL REMEDIATION TECHNOLOGIES for METAL AND ORGANIC REMEDIATION IN SOIL, SEDIMENT, SLUDGE, AND GROUND WATER

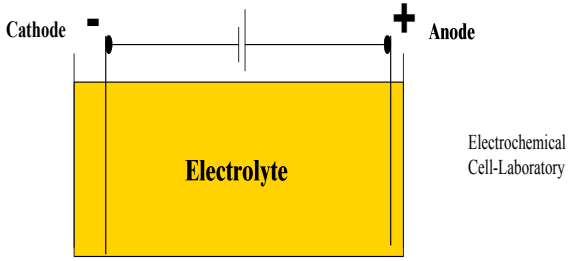
*Presented at*

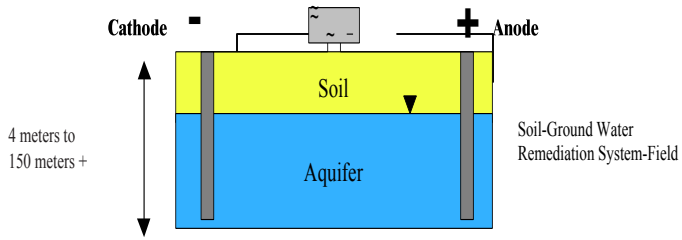
**4th Symposium on the Hydrogeology of Washington State**
**April 8-10, 2003 – Tacoma, Washington**

*prepared by*
*William A. McIlvride[2], Falk Doering, Ph.D[1]., Niels Doering[1], Donald G. Hill, Ph.D.[2], Joe L. Iovenitti[2], and J. Kenneth Wittle, Ph.D.[3]*

*For additional information, please contact Joe L. Iovenitti*
*Telephone (510) 450-6141 Fax (510) 547-5043 e-mail jli@weiss.com*

# PPESENTATION PURPOSE




**Soil -Sediment-Sludge-Ground Water System = ElectroChemical Cell**

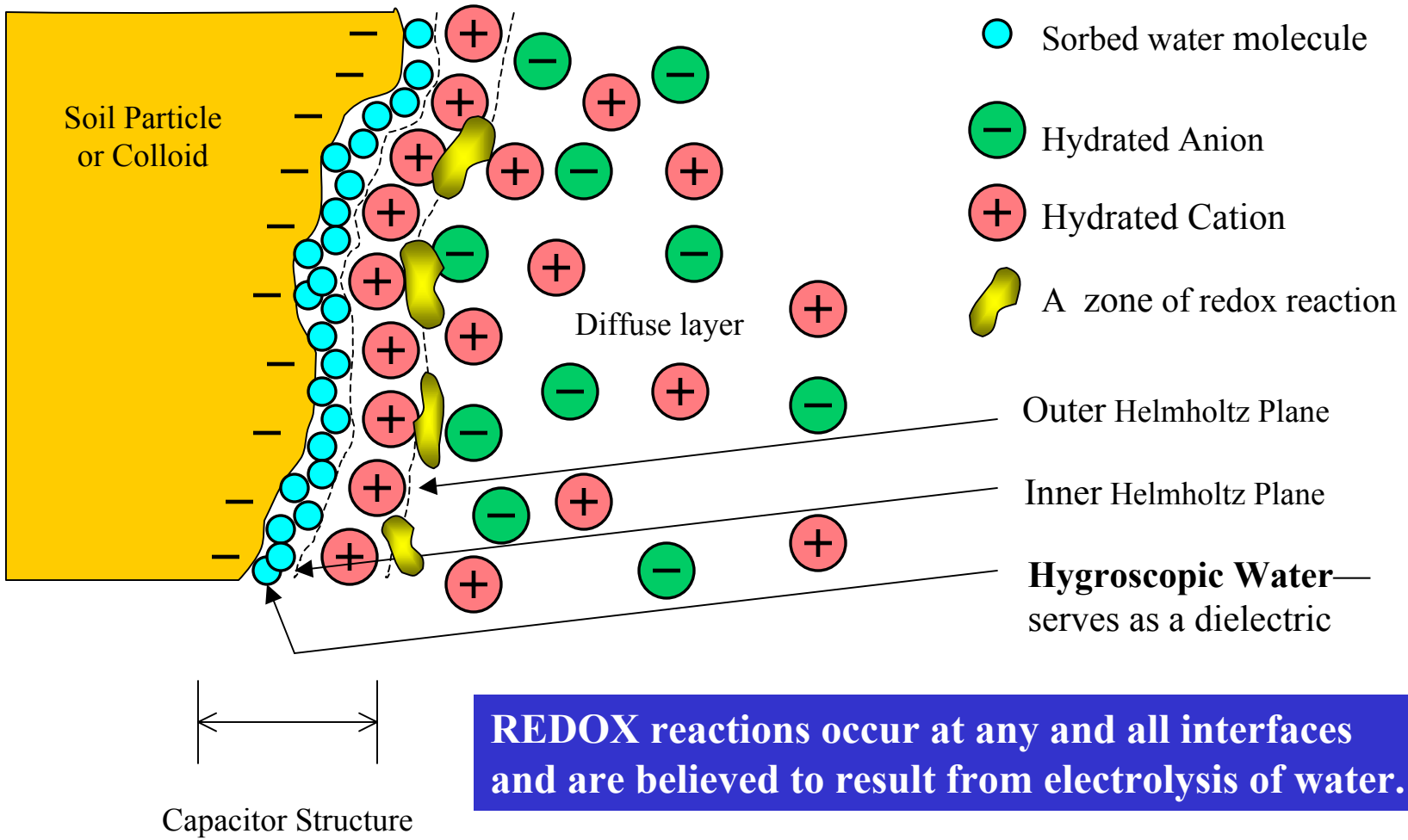
- **DESCRIBE** ElectroChemical Remediation Technologies (ECRTs) capabilities
  - (1) mineralize organics to their inorganic components (**ECRTs-ECGO**)
  - (2) enhance the mobilization of metals (**ECRTs-IC**)
  - (3) Numerous successful projects
- ECRTs are fast
  - **168 lbs. of mostly Hg deposited on both electrodes in 26 days; NETL lab test validated previous field results**
  - **PAHs destroyed in 100–120 days**
- Primary Mechanisms
  - Induced Redox Reactions
  - Electrolysis at Pore Scale

# INDUCED REDOX REACTIONS

- How Do They Occur?
  - Electrodes are placed in the soil/sediment where a low voltage and low amperage coupled DC/AC field is imposed
  - Soil particles and pore throats are electrically polarized
    - the soil acts as a capacitor, discharging and charging electricity, in response to the externally applied field
      - electrical discharge cycle = reduction
      - electrical charging cycle = oxidation
    - REDOX reactions occur at a high frequency throughout matrix

***No pumping or addition of chemicals required during ECRTs-ECGO or ECRTs-IC.***

# ECRTs PORE SCALE REDOX MODEL

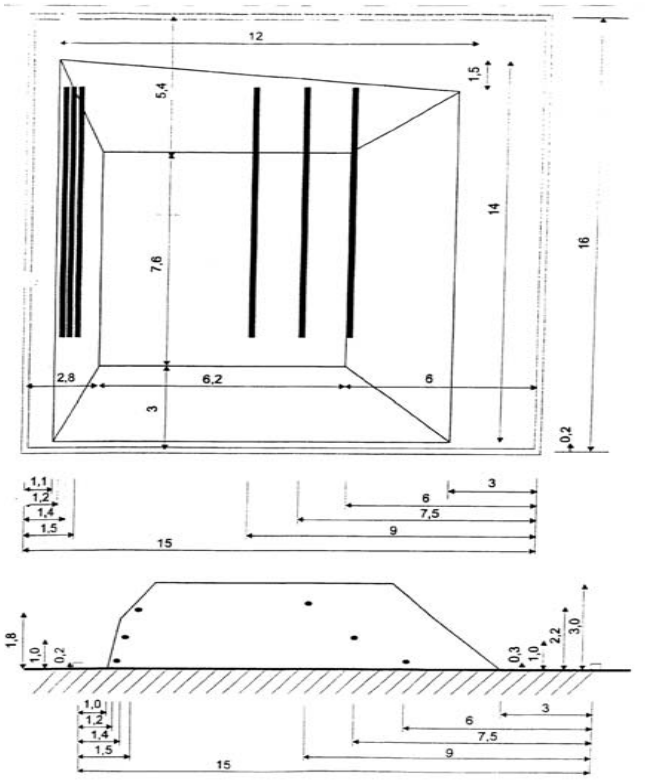



**REDOX reactions occur at any and all interfaces and are believed to result from electrolysis of water.**

# FUNDED ECRTs PROJECTS

- **Remediation Demonstration of PCBs in Soils/Sediment at an Upland Site, New York** (Fortune 100 Company)
- **Remediation Demonstration of Hg, Phenols, and PAH in Marine Sediments, Puget Sound, Washington** (Depart. of Ecology and USEPA SITE Program Project)
- **US DOE NETL Phase 1 Laboratory Test on Hg Contaminated Soil from Y-12 Plant at ORNL**; Waiting on Phase 2-Field Demonstration Notice to Proceed (US DOE)
- **Remediation Demonstration of PAHs in Lake Superior Fresh Water Sediments, Minnesota** (USCAE Detroit District, USACE WES, GLNPO, Minnesota Pollution Control Agency, University of Minnesota)
- **Evaluating Elemental Hg in Clay** at a NPL Site

# ENNS, AUSTRIA




**Plan View**

**Cross Section**
**(all figures in meters)**

500 tons of silty soil from unknown source. Particle sizes > 20 mm had been sorted out. Main pollutants: PAH EPA 1-16. Sampling and chemical analysis performed by independent accredited laboratory as per Regulator's instructions in compliance with German standard methods (DIN 38407 T8, HPLC with fluorescence detection). Sampling: one composite sample comprised of the 3 cores of 8 different locations (18–23 kgs). Terms of operation: 70/100 days at 75 Volts dc, 8 Amps

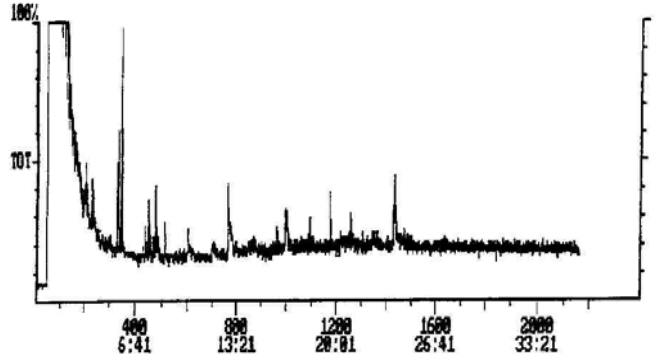
# ECRTs-ECGO, Enns Project

| Days | 1 | 36 | 70 |
|---|---|---|---|
| Naphthalene | 80.7 | 81.3 | 17.29 |
| Acenaphtylene | 35.2 | 44.1 | 0.98 |
| Acenaphthene | 9.8 | 22.2 | 0.6 |
| Fluorene | 38.6 | 503.1 | 1.13 |
| Phenanthrene | 326.8 | 83.7 | 7.35 |
| Anthracene | 47.8 | 11.9 | 1.45 |
| Fluoranthene | 107.5 | 23.4 | 2.98 |
| Pyrene | 230.2 | 81 | 8.38 |
| Benzo(a)anthracene | 71.3 | 17.6 | 1.48 |
| Chrysen | 81.8 | 17.9 | 2.04 |
| Benzo(b)fluoranthene | 50.7 | 9.6 | 2.09 |
| Benzo(k)fluoranthene | 47.3 | 4.2 | 1.21 |
| Benzo(a)pyrene | 110.3 | 17.9 | 3.75 |
| Indeno(123-cd)pyrene | 47.8 | 26.2 | 1.09 |
| Dibenz(ah)anthracene | 9.5 | 25.6 | 2.98 |
| Benzo(ghi)perylen | 59.5 | 37.9 | 0.54 |
| Total PAHs (1-16) | 1354.8 | 1007.6 | 55.33 |

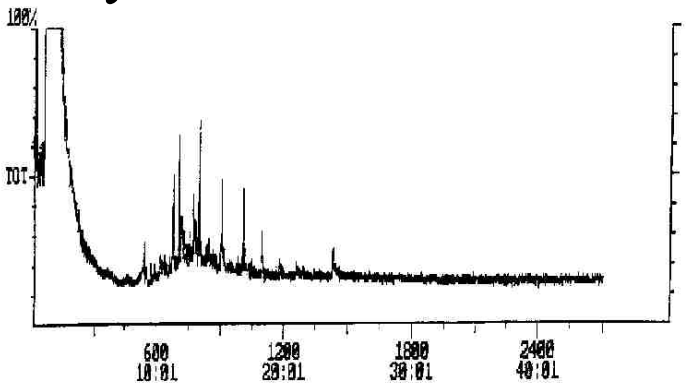
Note: All concentrations are in milligrams per kilogram (mg/kg)

# ECRTs-ECGO, Enns Project

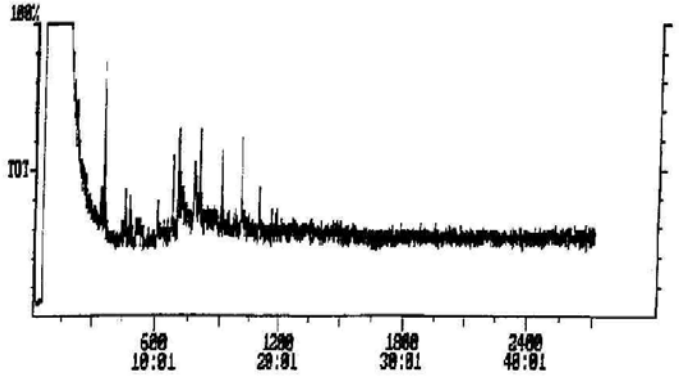
Baseline



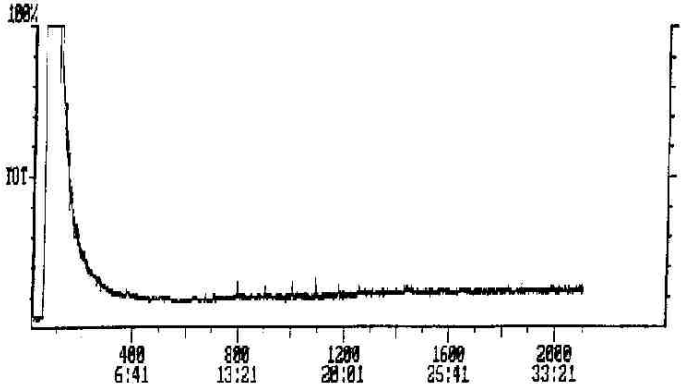

Day 70




Day 36



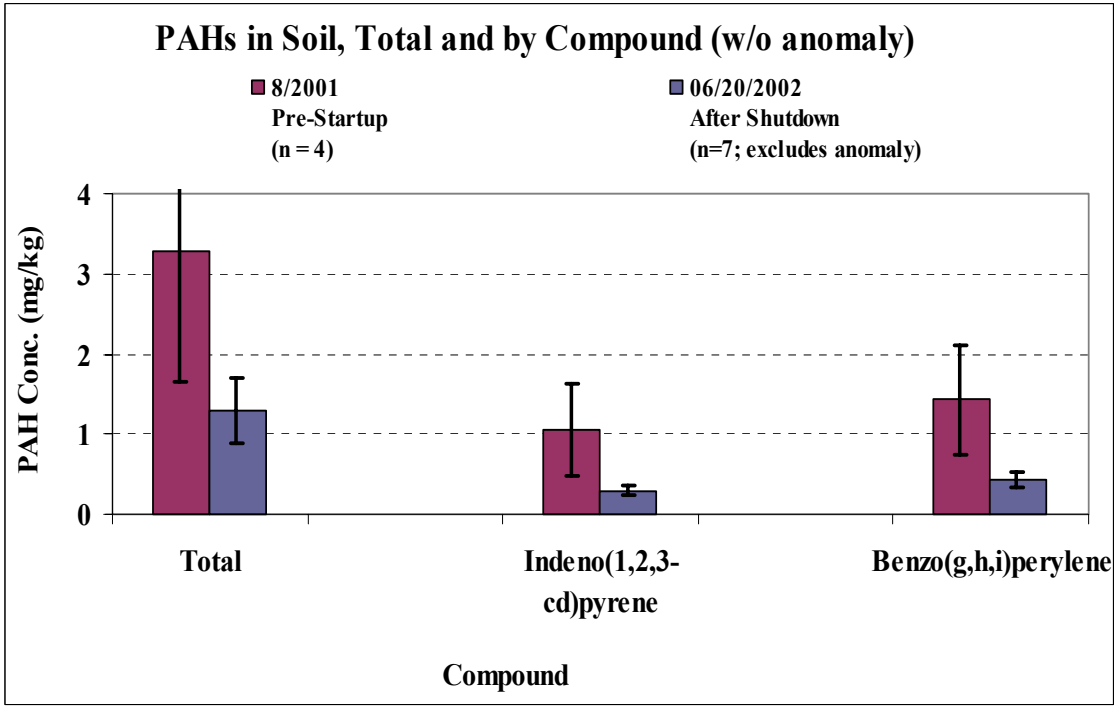

Day 100



# PCB DEMONSTRATION TEST

- ~120 Days of Non-Continuous Operation

- Preliminary data indicates that the PCBs may not have been destroyed due to electrical signal attenuation and operational / institutional issues



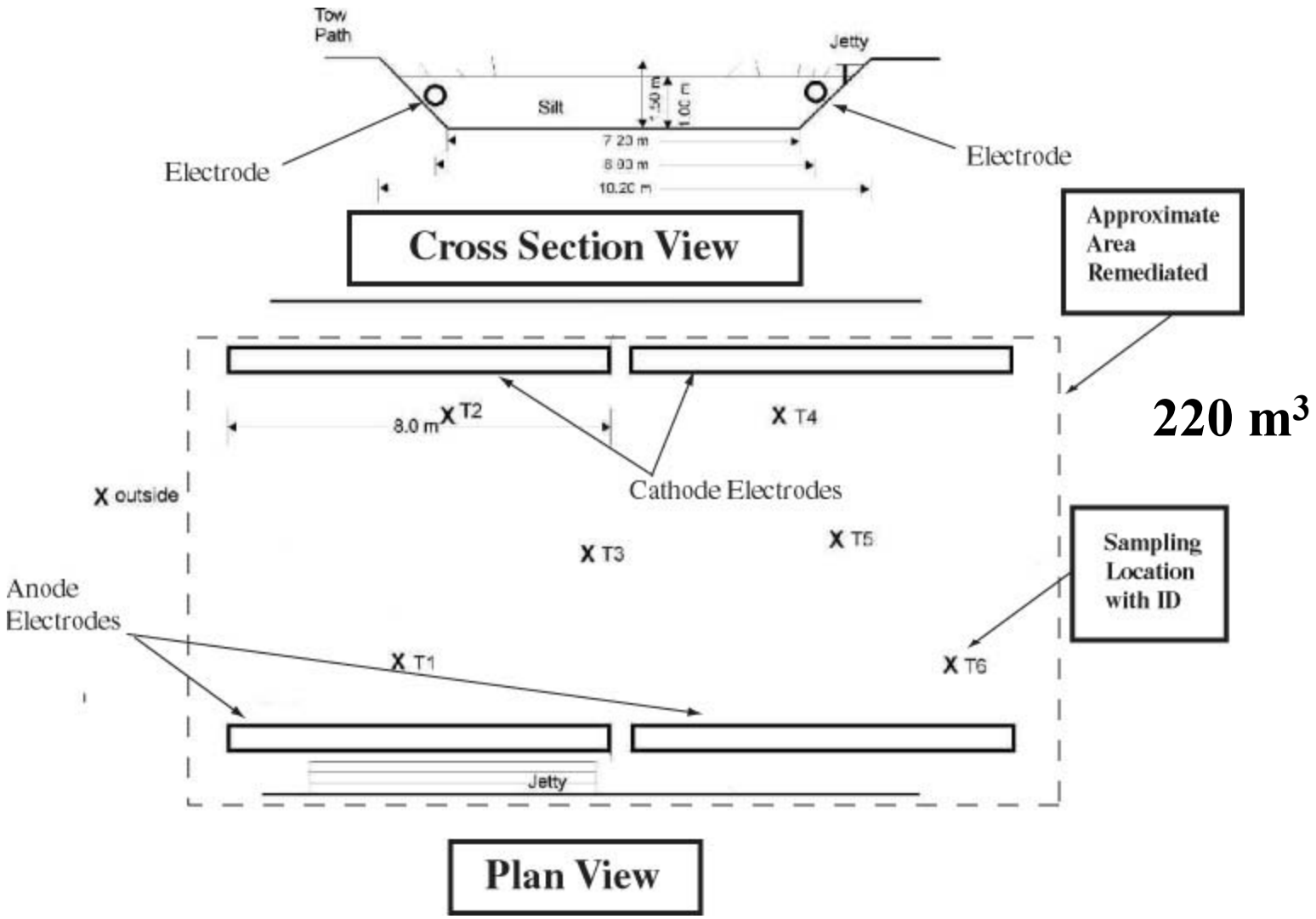

- > 60% of PAHs destroyed, excluding the two anomalous data sets; >70% 6-ring compounds destroyed

# UNION CANAL, SCOTLAND

- **Water TDS:** ~ 3.5 g/l mainly sodium chloride
- **Main Pollutants:** Elemental and methyl Hg
- **Electrodes:** Steel pipes 192 mm OD, each 8 m long
- **Power input:** 5.6 kW
- **Sediment:** silts

- **Initial Average Total Hg Concentration:** 243 mg\kg

# UNION CANAL, SCOTLAND

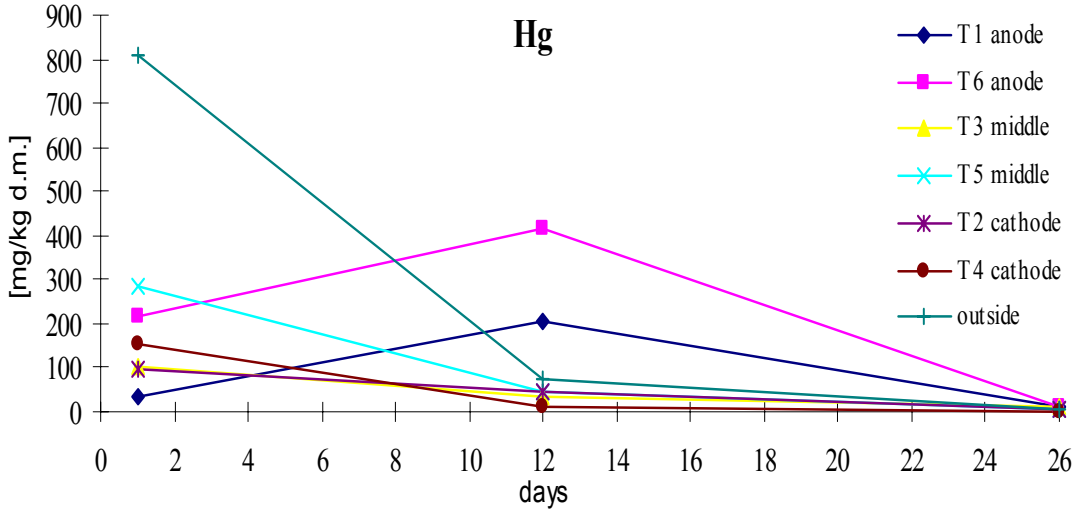


# UNION CANAL, SCOTLAND

**Results (all figures in mg Hg/kg dm)**

- **After 26 days of remediation 168 lbs of mostly mercury was deposited on both electrodes**
- **Post-remediation average total Hg Concentration = 6 mg/kg; cleanup objective was 20 mg/kg**

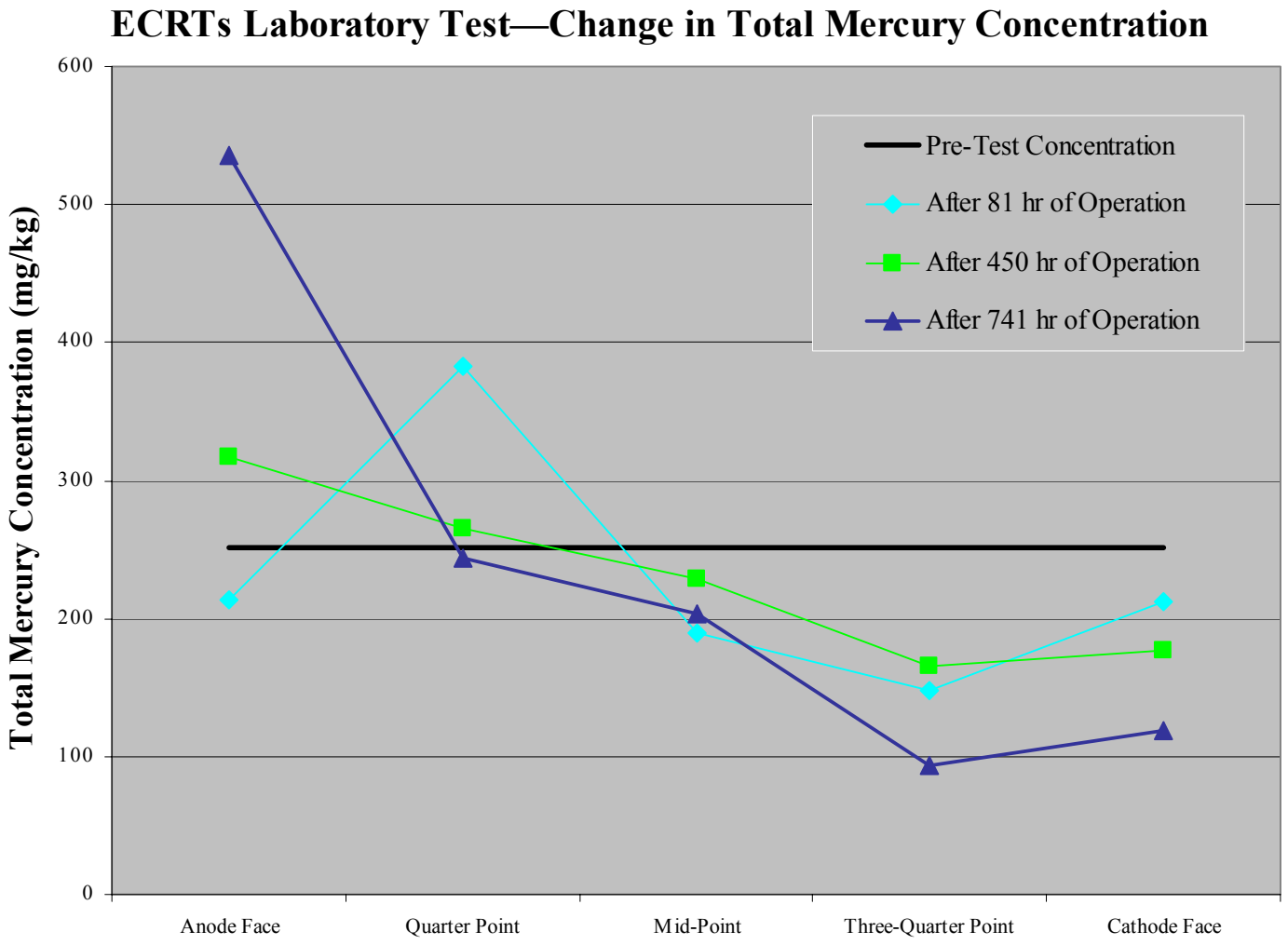
| Sample Location | Remediation Time (*days*) | | |
|---|---|---|---|
| | *1* | *12* | *26* |
| T1 anode | 33 | 204 | 11 |
| T6 anode | 218 | 417 | 9 |
| T3 middle | 102 | 36 | 11 |
| T5 middle | 282 | 48 | 6 |
| T2 cathode | 98 | 45 | 4 |
| T4 cathode | 156 | 9 | 0.7 |
| Outside | 809 | 73 | 4 |
| **Average Concentration** | **243** | **119** | **6.5** |




## Pb/As Data

**Considerable but unquantified amounts of As, Sn, and Zn were found on the anode; Pb reported but unquantified on cathode; no other metals reported on cathode.**

# Y-12 PLANT, OAK RIDGE TEST



# POST-TEST ELECTRODE OBSERVATIONS

| Observation | Graphite Anode | Carbon Steel Cathode |
|---|---|---|
| Gross Appearance | Yellow-White Deposits | Pitting and Corrosion |
| Microscopic Appearance | Deterioration and Yellow-White Deposits | Mercury Metal Droplets |
| Mercury Vapor | 0.002 mg/cu-m | 0.075 mg/cu-m |
| Mercury Analyses | 17.9–44.3 mg/kg | 4.2–11.6 mg/kg |

- Anode Mercury Species Are Not Volatile
- Cathode Mercury Species Are Volatile

# ECRTs–SUMMARY

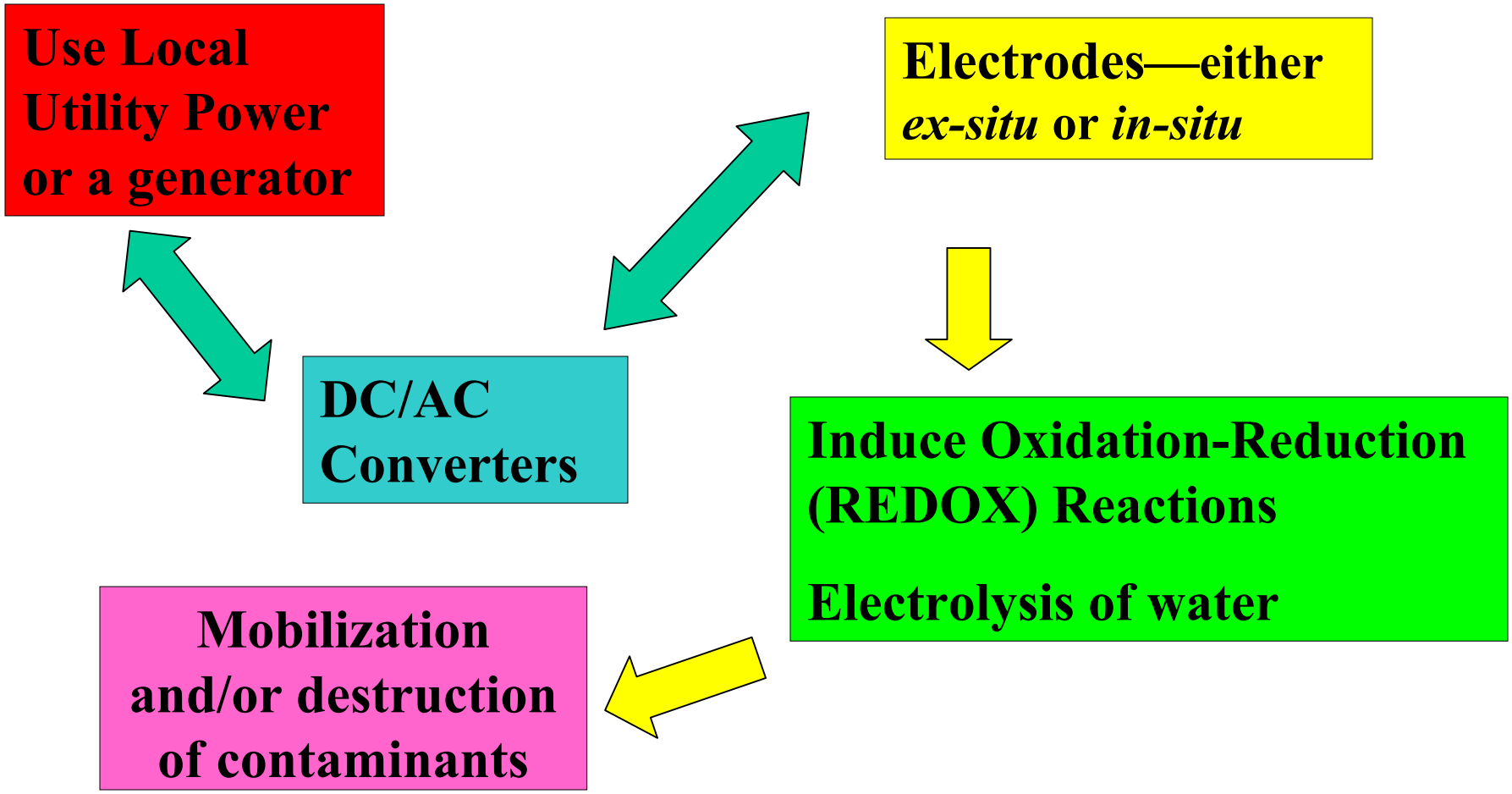
- ISO 9001 and 14001 Certified in Europe
- Patented in Europe and U.S.
- Destroys Organics in Place (**ECRTs-ECGO**)
- Enhances Mobilization of Metals (**ECRTs-IC**)
- Remediation Time = Typically Months
- Upland, General, Commercial Preliminary Engineering Cost Estimate (PECE) = **$135/yd$^3$ for 3,000 yd$^3$** to **<$35/yd$^3$ for >100,000 yd$^3$;** Aquatic **applications ~30% higher**
- *Ex-situ* and *In-situ* Applications, *In-situ Preferred*

# EXTRA SLIDES

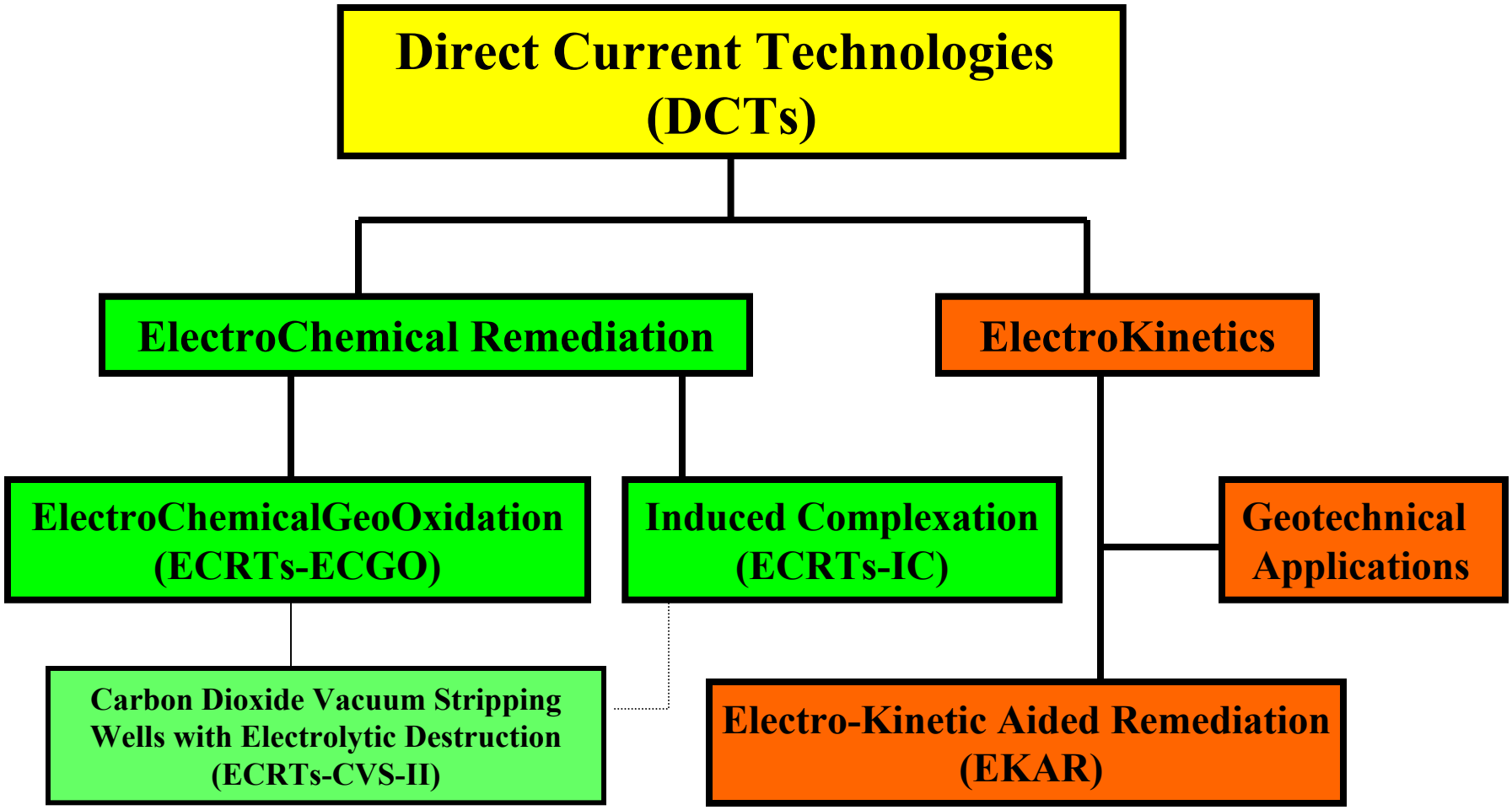
# COMPANY DESCRIPTIONS

- Weiss Associates
  - Established 1980, Offices in San Francisco Bay Area
  - Environmental Engineering, Geological & Management Firm
  - Traditional Consulting Services + Innovative Technologies
- P2-Soil Remediation, Inc.
  - Established in 1979, Offices in Stuttgart, Germany
  - ElectroChemical Remediation Company
  - **Remediated over 2 million metric tons of soil** in unsaturated, saturated, and aquatic environments, as well as ground water
- Electro-Petroleum, Inc.
  - Established in 1973, Offices in Wayne, PA
  - Direct Current Technology development firm

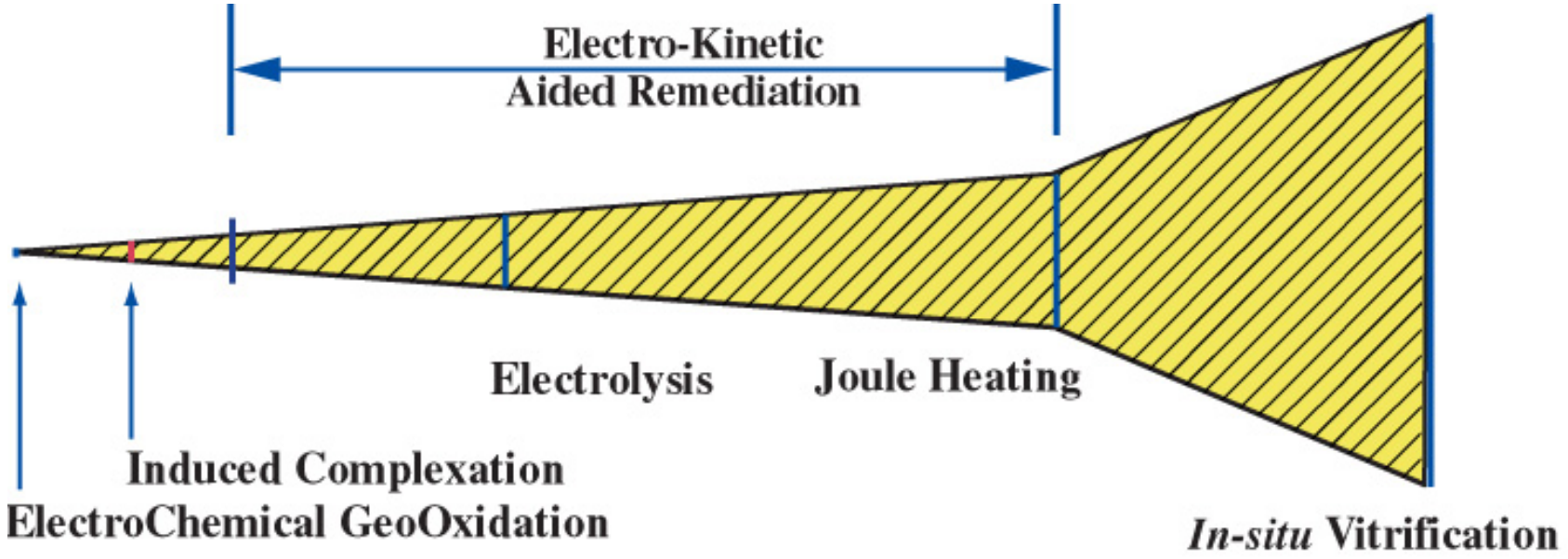
# PROCESS FLOW-ELECTRICITY



# DCTs

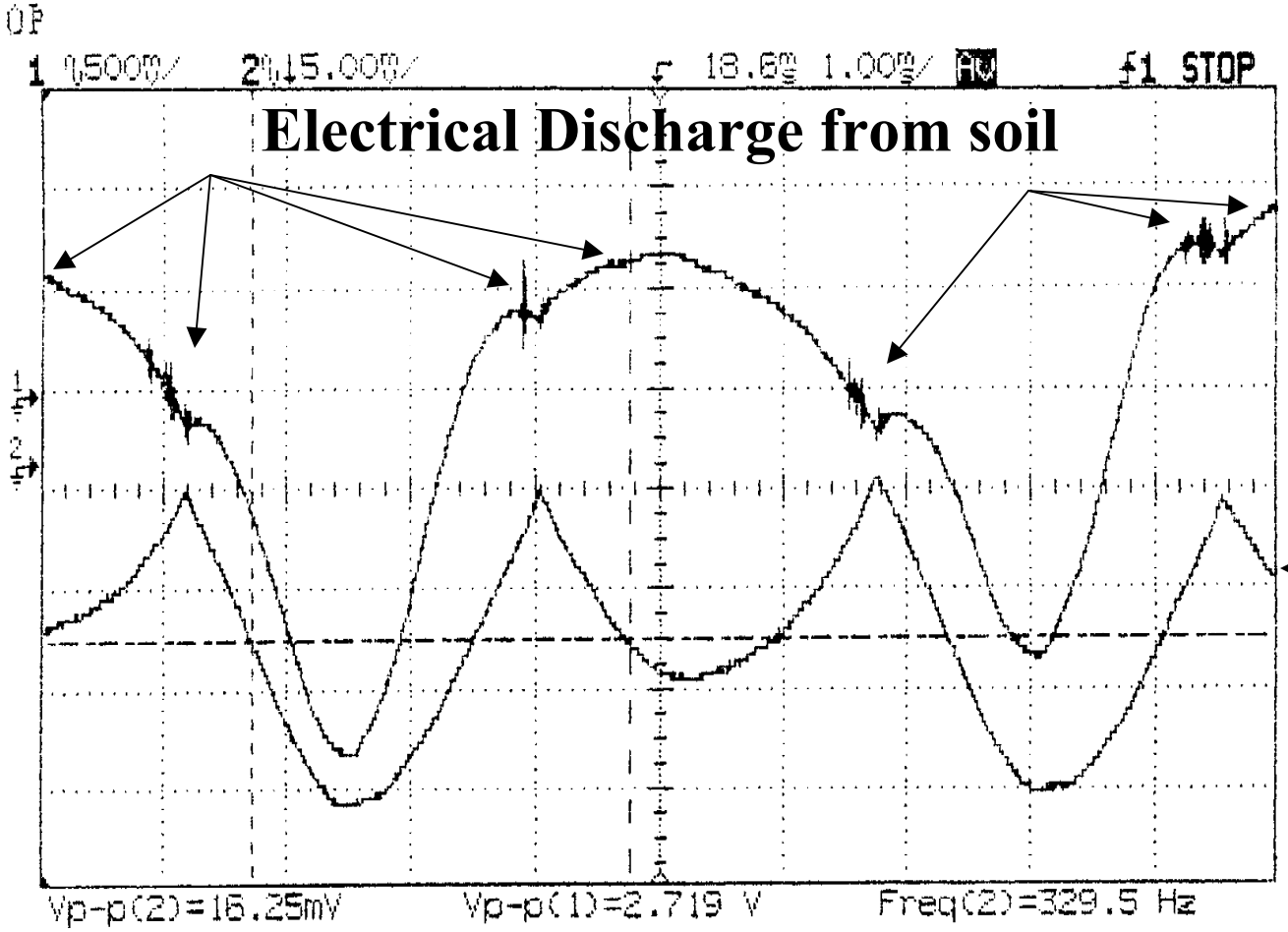


# ELECTRICAL ENERGY INPUT




- **ECRTs lie at the low end of the DCT continuum**
  - Range from induced REDOX reactions to mass transport to heating to melting of the soil/sediment

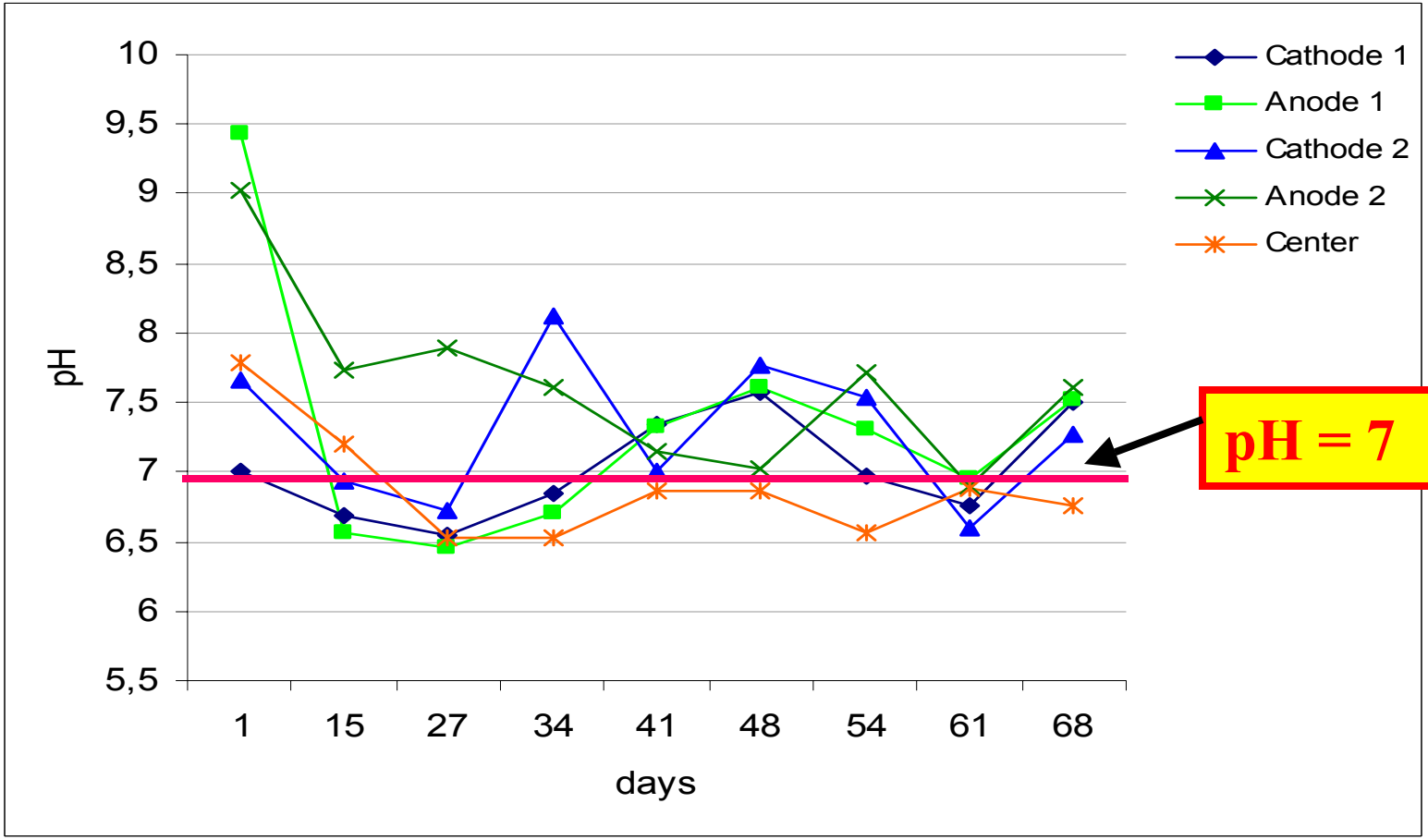
# ELECTRICAL DISCHARGES




Voltage in soil

Amperage in soil

# ECRTs-ECGO pH DEVELOPMENT




**Test site Deuben, FRG**

Unlike Electrokinetics, with ECRTs the pH stabilizes near 7 at both electrodes

# ECRTs-IC

- Electrodes are placed in the soil/sediment where a low voltage and low amperage coupled DC/AC field is imposed and the soil/sediment is polarized
- Inorganic compounds are complexed through the ECRTs-ECGO process and the complexes and ions are transported to the electrodes by Electrokinetics
- Metals ions are deposited into the electrodes
- Remove electrodes and disposed or metals are recycled

# ECRTs EFFECTIVENESS

| Contaminant | Unsaturated Zone | Saturated Zone / Sediments |
|---|---|---|
| Metals | Yes | Yes |
| Radionuclides | Yes[1] | Yes[1] |
| Sorbed Organics | Yes | Yes |
| Dissolved Organics | Yes | Yes[2] |
| Free-Phase Organic (NAPL) | Yes | Yes |

[1] Radionuclides have not, to date, been remediated with ECRTs but are included by inference.
[2] Effectiveness is a function of aquifer grain size. Reaction rates are inversely proportional to grain size.

# ECRTs-ECGO, Enns Project

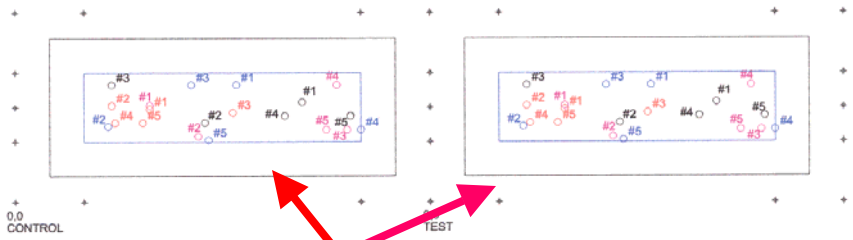
| RT | FE | Compound |
|---|---|---|
| 232 | 9 | Naphthalene |
| 480 | NQ | Acenaphthylene |
| 528 | 2 | Acenaphthene |
| 602 | NQ | Fluorene |
| 762 | NQ | Phenanthrene |
| 765 | NQ | Anthracene |
| **796** | **33** | **Dimethylcyclohexane (Degradation Products)** |
| **903** | **36** | **Propanoic acid, Dimethyl-, methylester (Degradation Products)** |
| 936 | NQ | Fluoranthene |
| 997 | NQ | Pyrene |
| **1002** | **51** | **Propanoic acid, Dimethyl-, methylester (Degradation Products)** |
| **1092** | **64** | **Propanoic acid, Dimethyl-, methylester (Degradation Products)** |
| **1175** | **44** | **Propanoic acid, Dimethyl-, methylester (Degradation Products)** |

NQ = Not Quantifiable

- GCMS Results after 100 Days of Remediation

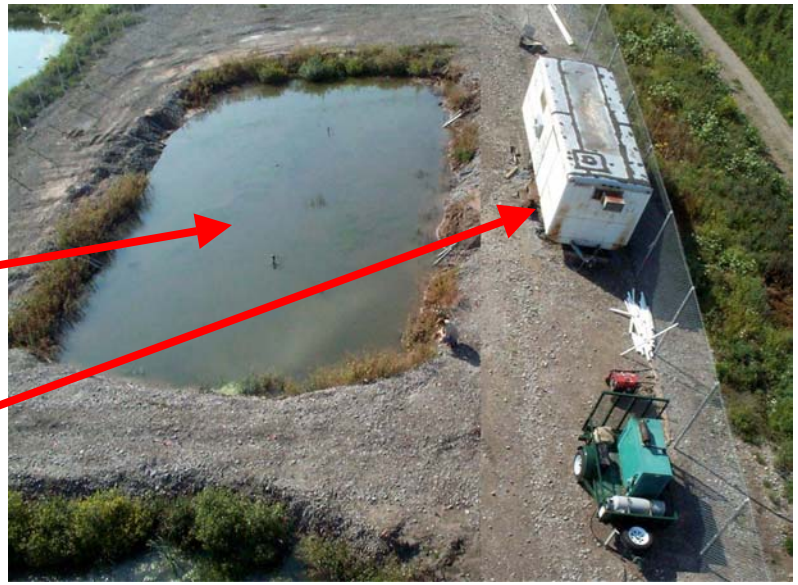
# ERIE PIER CDF, LAKE SUPERIOR

Control Test




**Two Cells Created**

**Confined Disposal Facility (CDF)**

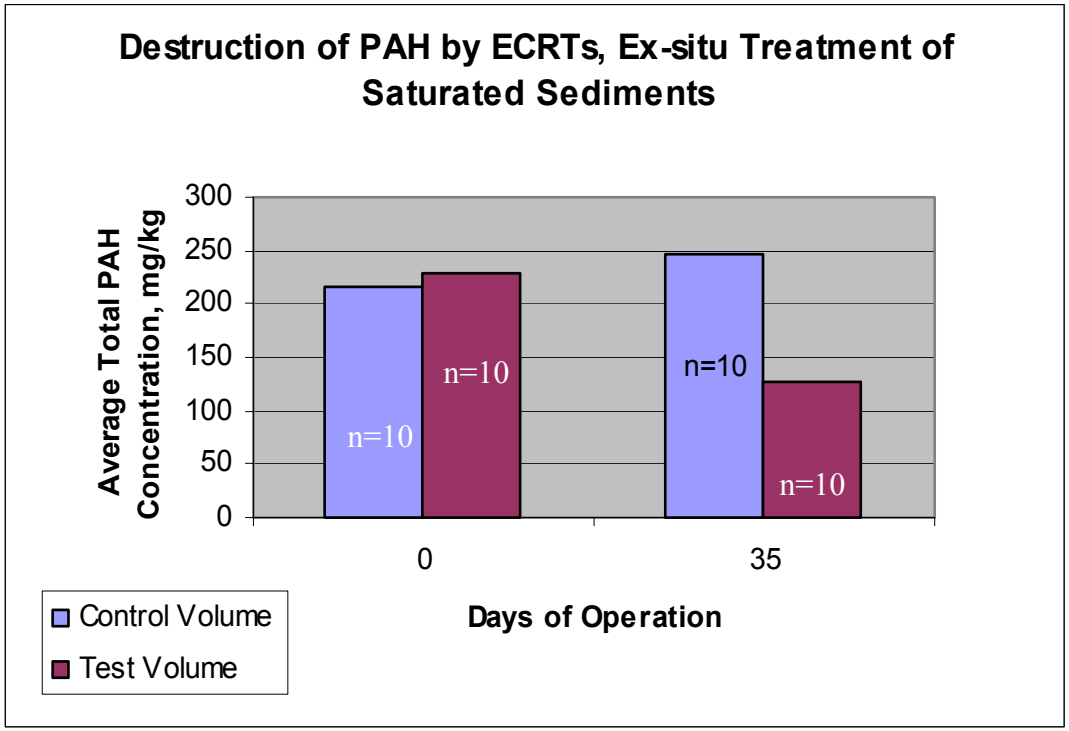


**Test Cell**

**Power Supply**

# ERIE PIER, IN-PROGRESS DATA

**Average Total PAH (USEPA 1-16) Concentration (mg/kg) for Baseline (Day 0) and 35 Days into the Remediation (Day 35); total remediation time is about 100 days**



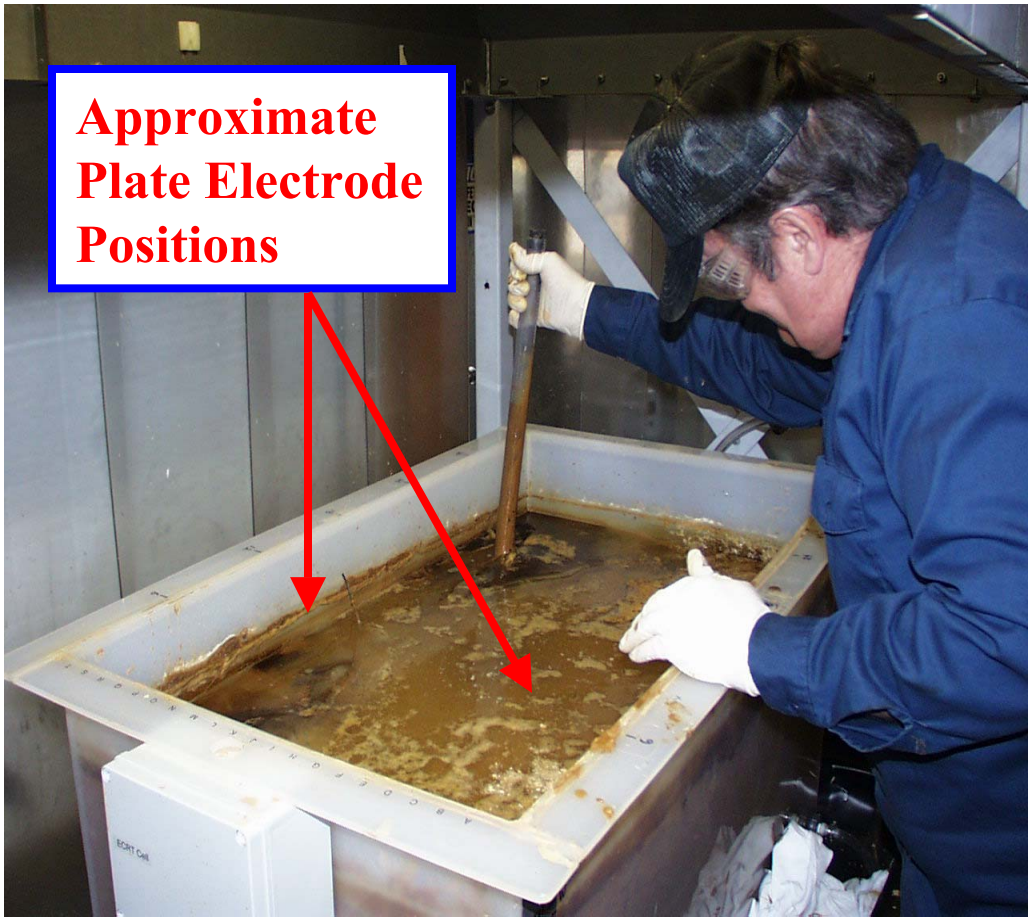

**After 35 days of remediation Total PAHs decreased by ~45% relative to initial sampling test cell.**

Average Total PAH Concentration, mg/kg

| | Days of Operation | | |
|---|---|---|---|
| **CDF CELL** | **0** | **35** | **delta** |
| Control | 216 | 247 | 14.4% |
| Test | 228 | 127 | -44.3% |

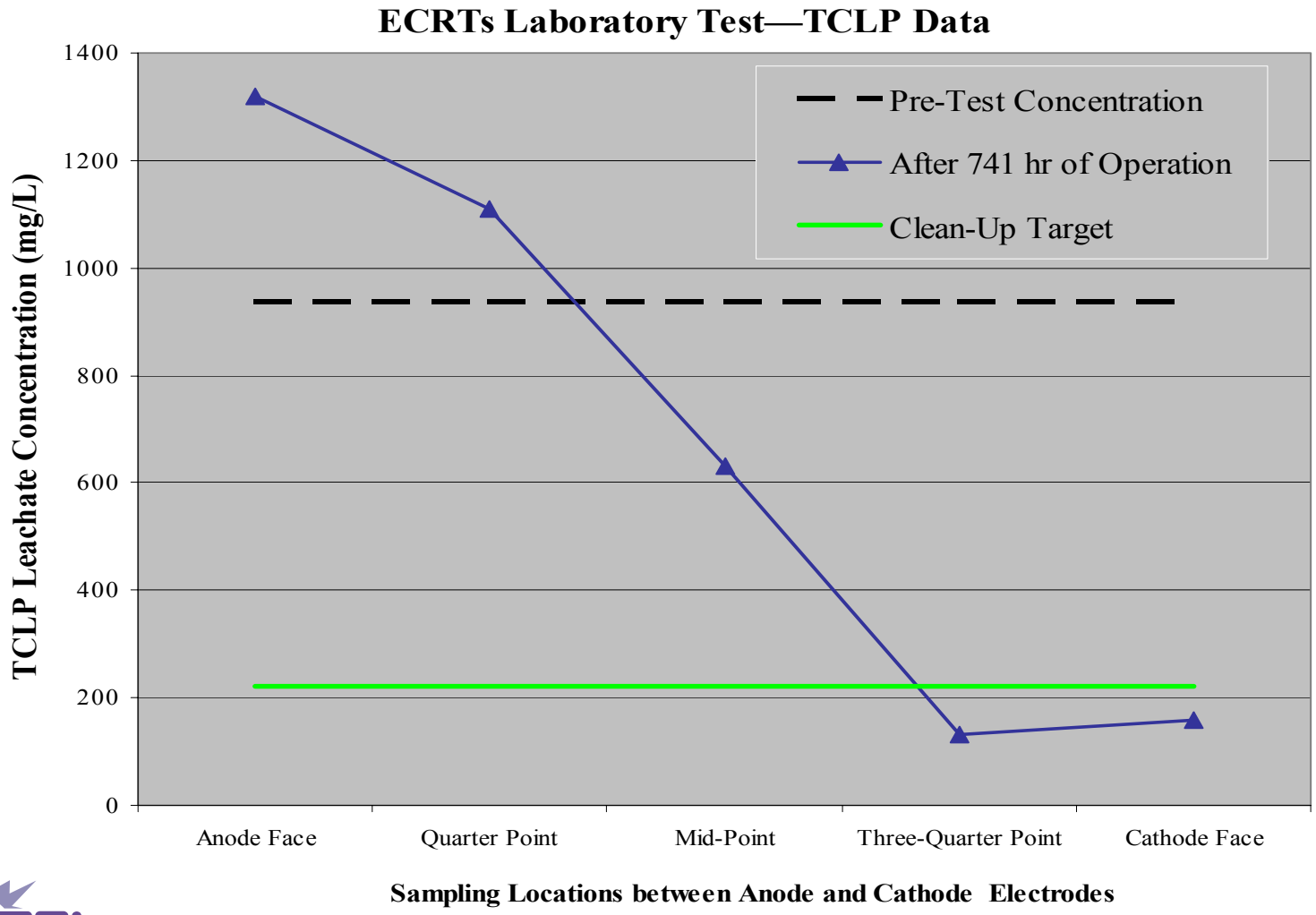
# Y-12 PLANT, OAK RIDGE

## ECRTs Mercury Remediation Test

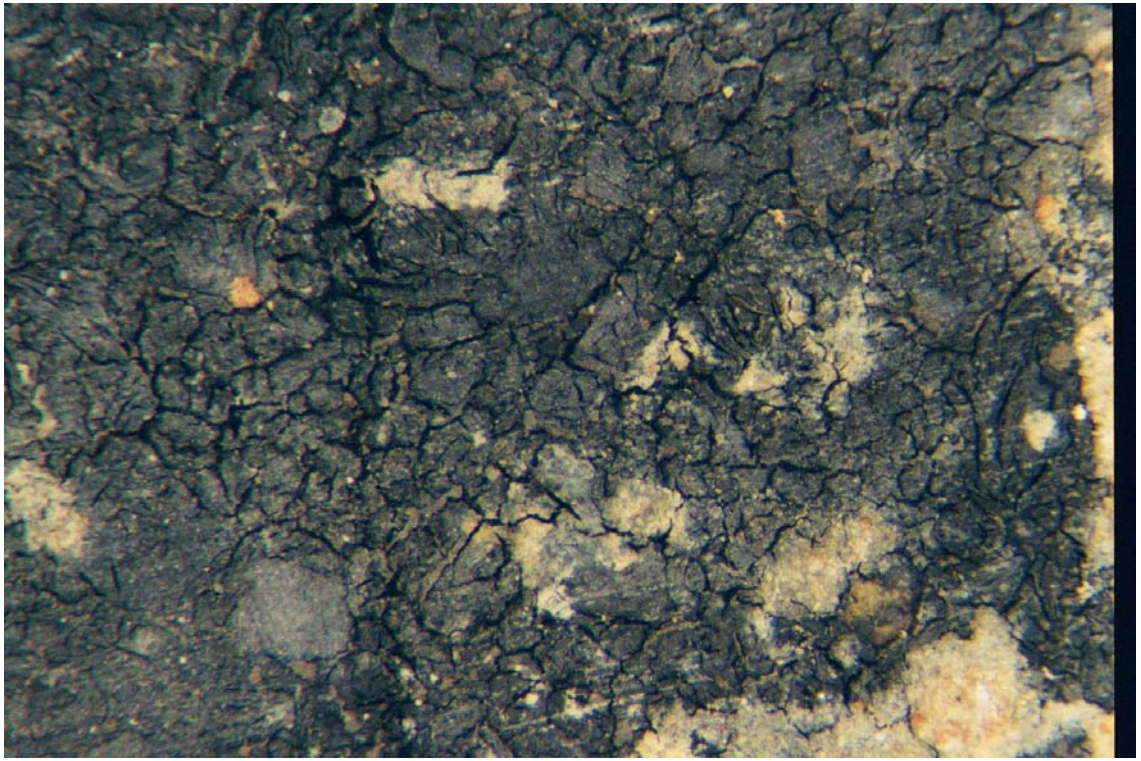



- Initial Hg concentration 252 mg/kg
- Sampling after 81, 450, and 741 hrs of operation at sites between anode and cathode electrodes
- Sampling Locations at the Anode Face, Quarter Point, Mid-Point, Three Quarter Point, and Cathode Face

# Y-12 PLANT, OAK RIDGE TEST

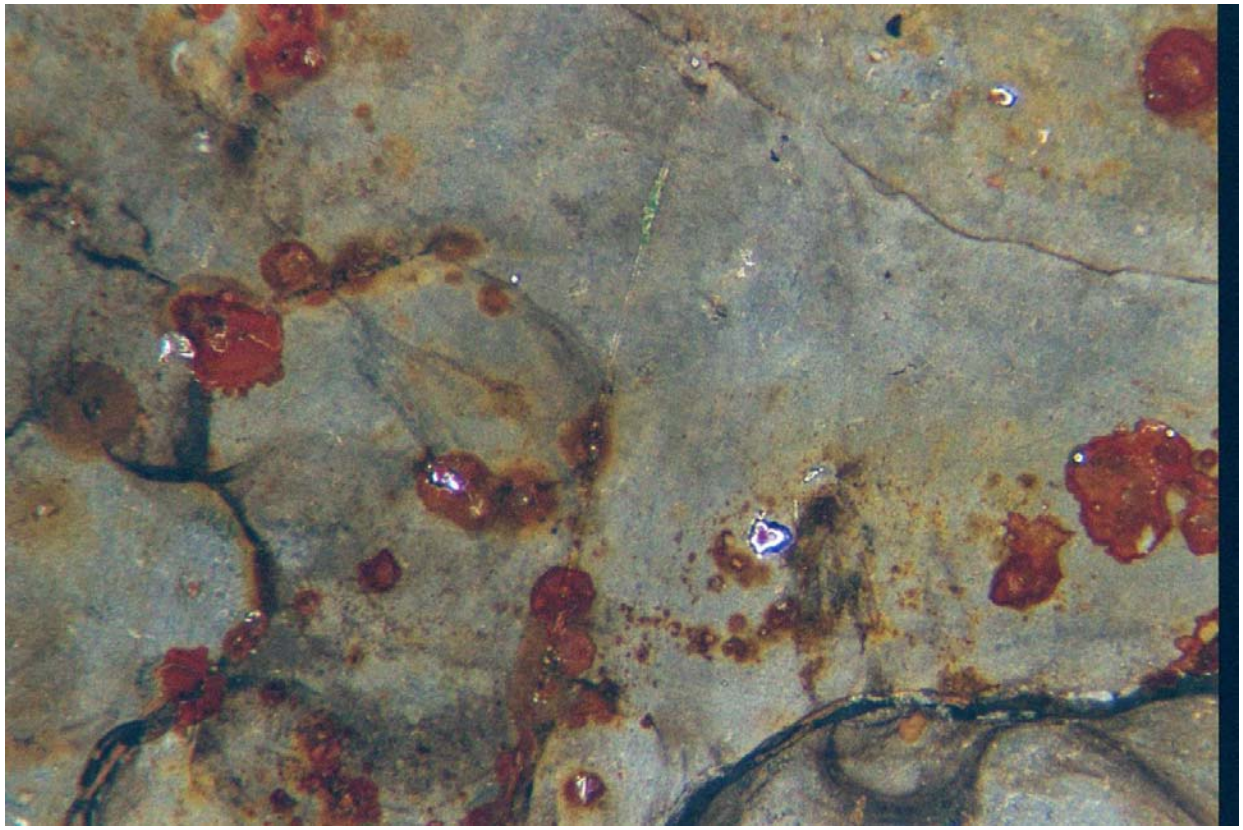


# ANODE PHOTOMICROGRAPH



- Deterioration of Graphite Face and White Deposits, ~30X

# CATHODE PHOTOMICROGRAPH



- Droplets of Metallic Mercury, ~30X

# TEST CELL MERCURY MASS BALANCE

| Item | ECRTs-IC Test Cell Results |
|---|---|
| Initial Mercury in Test cell (gm) | 52 |
| Total Mercury at Cathode (gm) | 5.4 |
| Total Mercury at Anode (gm) | 23 |
| Total Recovered Mercury (gm) | 28.4 |
| Mercury Recovery (%) | 54.62 |
| Total Mercury still in Test Cell (gm) | 22.7 |
| **Accounted Mercury (%)** | **98.27** |

# EFFICIENCY COMPARISON

| Measure | NETL Bench-Scale Test | Union Canal | Montluçon |
|---|---|---|---|
| Mercury Recovery (% Pre-Test) | 54.6 | 97.5 | 99.6 |
| Mercury Recovery Rate (gm/hr) | 0.038 | 143.77 | 58.33 |
| Mercury Recovery Power Cost Rate ($/gm) | $0.42 | $0.0039 | $0.0039 |

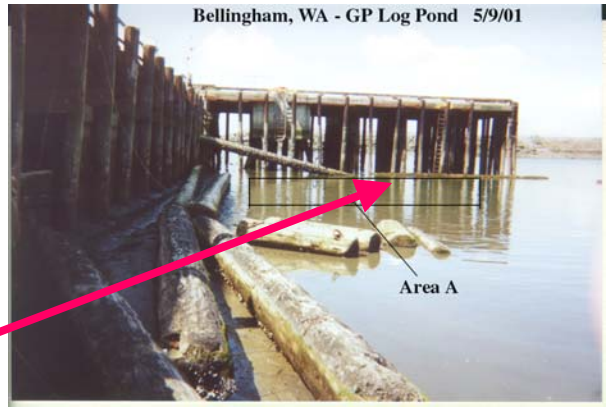
# Y-12 PLANT, OAK RIDGE

## LABORATORY TEST RESULTS

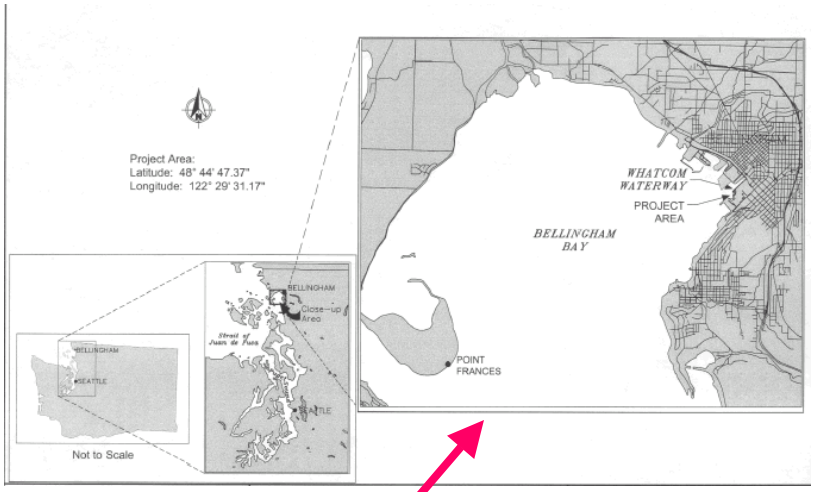
- Hg Contaminated Soils Saturated with Fresh Water Were Successfully Treated to below the DOE Site Imposed TCLP Cleanup Level
  - Mercury species reported by DOE Site to be present include:
    - mercury chloride, mercury nitrate, mercury sulfide, elemental mercury, and methyl mercury
    - No detailed Hg speciation conducted during test reported herein
- Laboratory Results Corroborate Fresh and Brackish Water Field Remediation Results

# Puget Sound In-Water Demonstration

- Joint WA Depart. of Ecology / USEPA SITE Program Project
- Hg, Phenols, and PAHs principal COCs



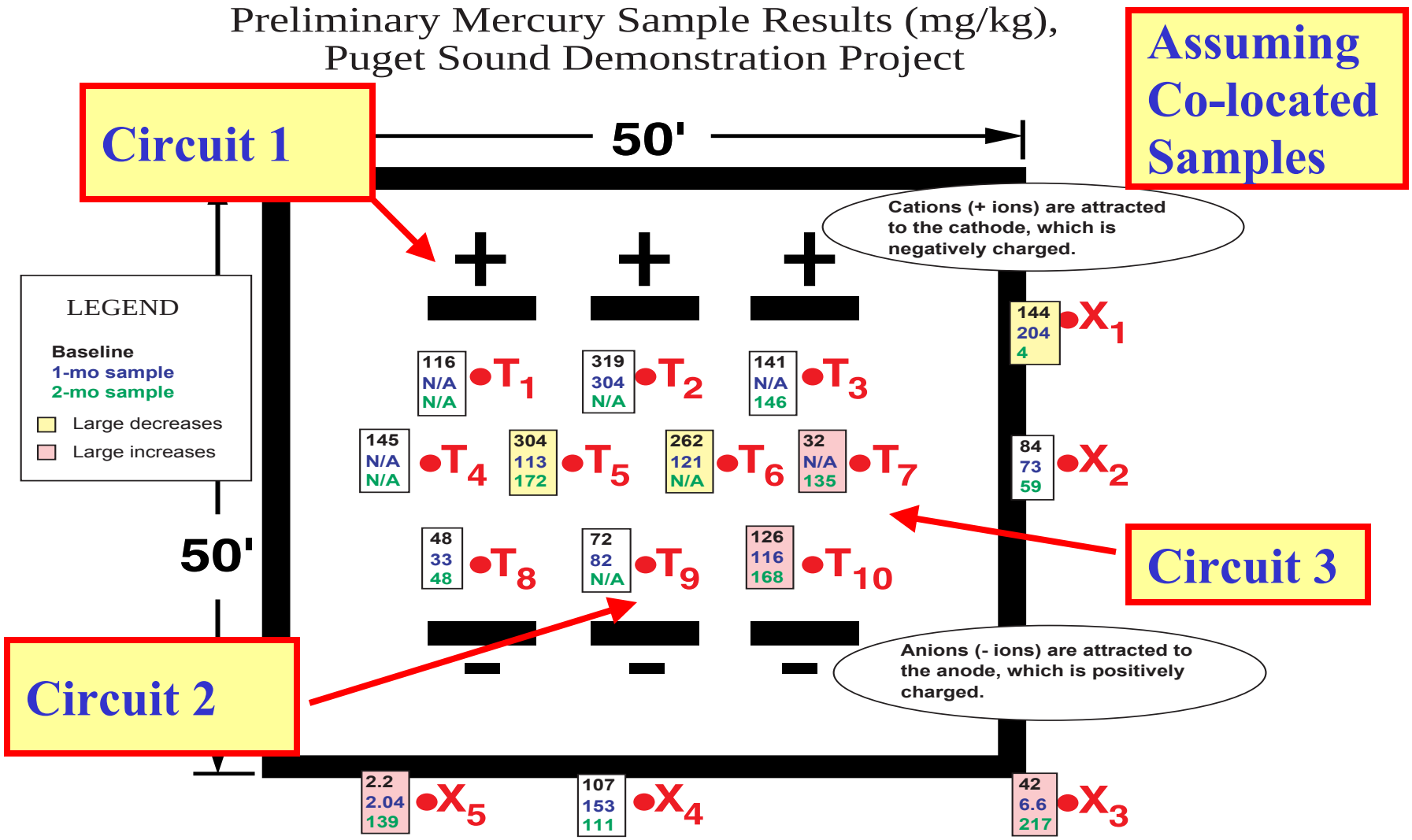

**Demonstration Location**




**Location Map**

**Installing Electrodes**

# In Progress Results



# In Progress Results